The Quantum View of the World

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Introductory Remarks

In the early days of QM intense discussion of philosophical issues (the analysis of concepts, principles and ultimate presuppositions) of the theory. This culminated in 1935 with EPR debate between Einstein and Bohr. Bohr (and Copenhagen complementarity interpretation) were officially declared the winner. Bohr reigned supreme until the 1960s, except for the efforts of Bohm to construct h.v. models of QM. This was partly due to the influence of von Neumann's no-go theorem proved in the oft-cited but little read Mathematische Grundlagen der Quanten Mechanik (1932).

Main technical advance was Gleason's theorem (1957) on possible prob measures that could be defined on the projection lattice of a Hilbert space. This ~~[illegible]~~ proved to be the key to the work of Bell and Kochen and Specker (1967). A parallel development was the discovery of a ~~[illegible]~~ non-locality property of h.v. theories in 1964. This was the Bell Inequality which lead to many experimental tests culminating in the work of Aspect, Dalibard and Roger about to be announced.

Notice different reactions here as between physicists & philosophers.

Aspect's result expected by physicists — regarded by many philosophers as revolutionary

minimal instrumentalist (statistical) interpretation of QM as used by most physicists. Philosophers want to understand

what was going on in QM
to provide if you like A Quantum View of the World

I am going to begin with the problem
of non locality

The problem situation here is that in
some sense the EPR phenomenon
in QM appears to involve nonlocality,
instantaneous action at a distance and
this is supposed by to be ruled out
by special relativity.

By EPR phenomenon I mean the
correlation properties of spatially
separated systems in certain
states involving the superposition
of products of 1 particle wave functions
these are typified by the singlet
spin wave function for two spin ½ particles

$$\Psi_{singlet} = \frac{1}{\sqrt{2}}\left(\alpha(1)\beta(2) - \beta(1)\alpha(2)\right)$$

α is the state with z-component of spin $\frac{1}{2}\hbar$
β . . . . $-\frac{1}{2}\hbar$.

this would describe for example the spins
of two protons emerging from a low-energy
(S-wave) scattering event (according to
the Pauli Principle). Measuring of the
spin-component of one particle apparently
changes the state of the other particle
in a non-local manner.

N.B. $^2P_{\text{singlet}}$ is a N.R. wave function but it is the exact form of the relativistic version of the 2-body spin wave function related to an appropriate frame of reference for a slowly moving 2-body system

In order to proceed we distinguish 3 versions of the individual particle interpretation of QM which call A, B & C.

This gives

3 views on observables not in an eigenstate

A) Sharp unknown value

B) unsharp or 'fuzzy' value

C) Undefined or meaningless value.

cf QM is not mysterious, mysterious with new concepts like potentiality or latency, and mysterious in recognizing limitations in the applicability of old concepts.

3 views on what measurement does

A) Pre-existing value revealed

B) Potential or latent value actualized

C) Undefined value becomes defined.

How is this change brought about?

1) Interaction with a physical instrument

2) Action of human consciousness

The EPR Argument (1935)

This is an argument for the incompleteness of QM.

EPR takes as necessary condition for completeness: Every element of reality has a counterpart in the theory, associated with it.

They take as sufficient condition for an element of reality: If without disturbing a system we can predict with certainty the value of an observable then already, before the prediction, there exists an element of reality corresponding to that observable.

The EPR argument is based essentially on view B and shows that this view is incomplete in the sense that even two non-commuting observables do have sharp values (not referred to in position B).

So the argument wishes us to turn to position A.

But the argument involves a locality assumption

Locality: unsharp → sharp forbidden 'at a distance'

(Distinguish Bell and Einstein sense of 'at a distance'.)

Bohr's response to EPR was to query whether it showed not with what view C and use

Locality$_2$: undefined → defined 'at-a-distance' forbidden

But also this principle could be denied since no physical non-locality involved.

EPR showed that

QM + Locality$_1$ → Incompleteness (assuming view B)

or QM → Non-locality$_1$ or Incompleteness

This is the Einstein dilemma {EPR ~~[illegible]~~ grasped the 2nd horn / The 1st horn leads to the EPR Paradox}

But Bell showed (1964)

Completeness → non-locality$_3$ (i.e. view A)

where

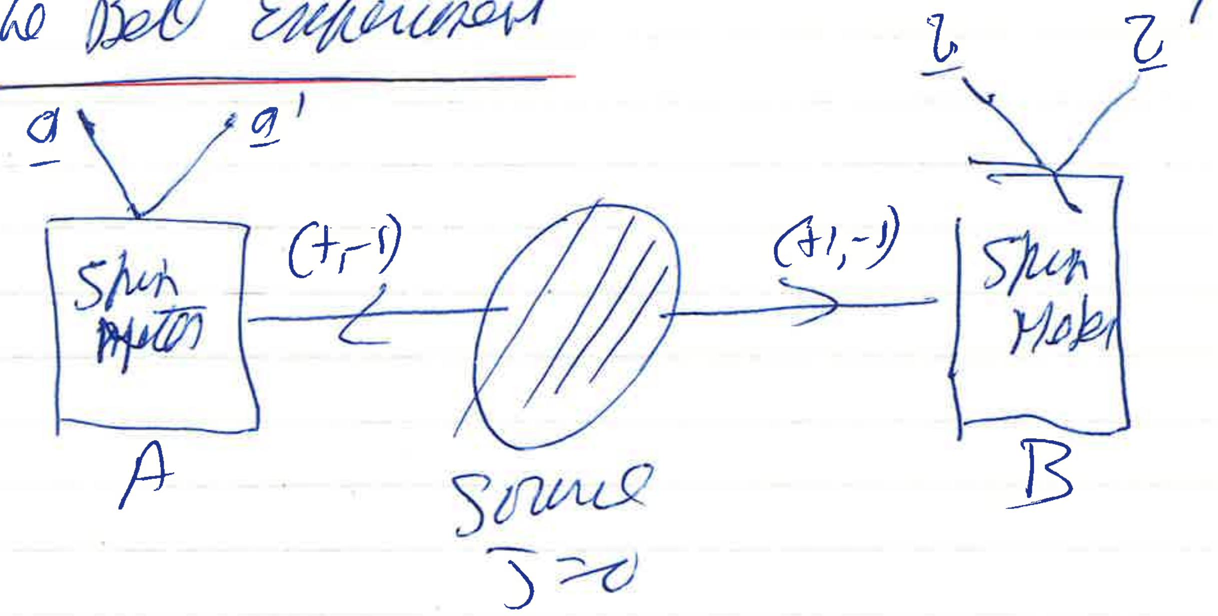
Locality$_3$ sharp → sharp at-a-distance forbidden

The Bell Argument

Locality$_3$ → Bell Inequality which is contradicted by QM (and by experiment)

cf. in particular Aspect, Dalibard and Roger (P.R.L. (1982))

The Bell Experiment



a_n denotes spin-component of A-particle parallel to direction $\underline{a}$ for n^{th} pair of particles

similarly a_n', b_n, b_n'.

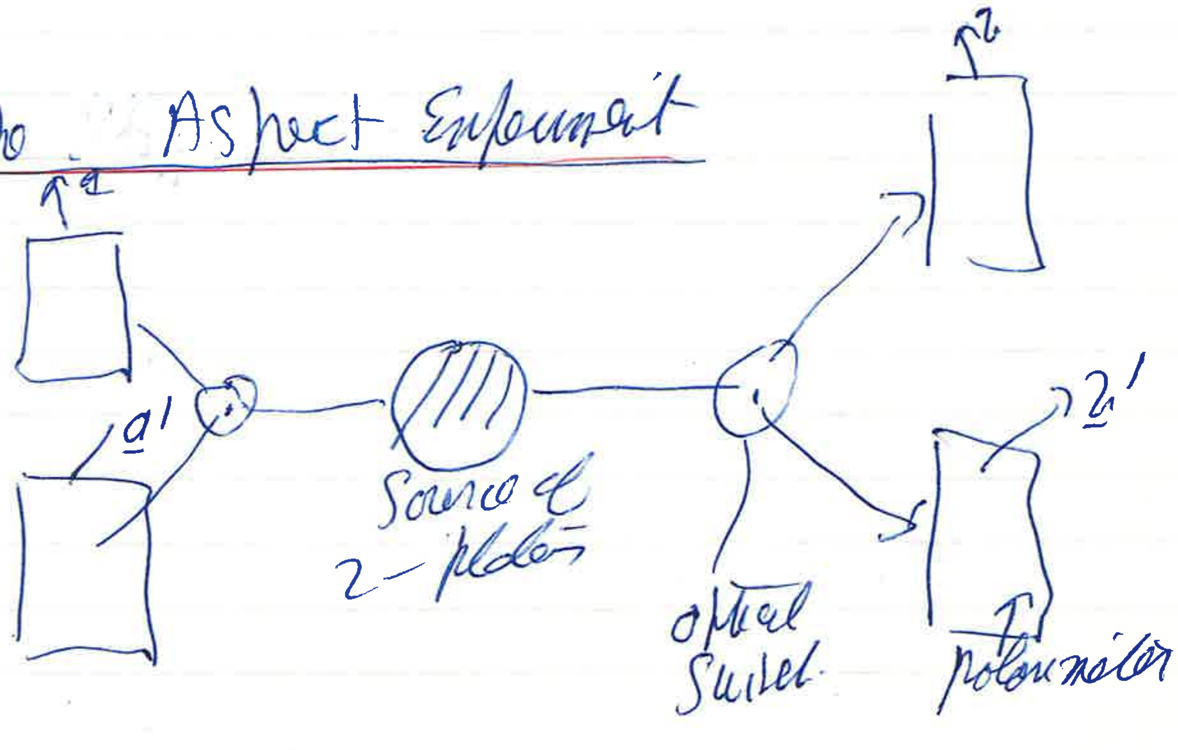
Then define correlation coefficients

$$C(a,b) = \lim_{N\to\infty} \frac{1}{N} \sum_n a_n b_n \quad , \text{etc}$$

The Bell Inequality reads

$$|C(a,b) + C(a,b') + C(a',b) - C(a',b')| \leq 2.$$

The Aspect Experiment



The Stapp-Eberhard Approach

Can we reformulate argument for Bell Inequality in terms of measurement results, so it would apply also to view B.

Locality$_4$: Classical state of macroscopic object cannot be altered at a distance.

The Principle of Local Counterfactual Definiteness (PLCD)

Result of an unperformed experiment has a definite result which does not depend on the setting of a remote piece of apparatus.

(So $\neg$ PLCD $\rightarrow$ $\neg$ Loc$_4$ for Stapp-Eberhard)

But in a genuinely indeterministic situation (as in view B) PLCD is suspect.

Contrast a) clock striking as 9 runs my hand
b) the alarm clanging as a sense my hand.

Even if same experiment is re-run, would I expect same result (counterfactual).

Statistical NonLocality

No statistical effects produced at a distance — tagging information at the wrong location — Oxford letters, roses in Chelsea example.

— Impossibility of the Bell Telephone

Is Locality Violated in EPR.?

Violates / View	Loc$_1$	Loc$_2$	Loc$_3$	Loc$_4$	Loc$_5$
A	no	no	yes	yes	no
B	yes	no	no	no	no
C	no	yes	no	no	no.

N.B. Locality problem does not arise in statistical or empirical approach since Loc$_5$ not violated.

Query Does Violation of Locality conflict with S.R.?

Violation of Loc$_3$ more serious than Loc$_1$

cp Shimony (1978) peaceful coexistence in case of violation of Loc$_1$.

cp also does S.R. prohibit intertemporal effects Tachyon theory, Causal loop paradoxes

Kochen-Specker Paradox

So with some form of non-locality we can retain realism. But can we? There is another difficulty posed for realism by the Kochen-Specker Paradox. They demonstrated a purely algebraic problem about attributing values to observables.

Kochen & Specker showed the following.

non A + ~~[illegible]~~ + (FUNC) $\Rightarrow$ contradiction.

[VR says. $P_Q^{\phi}(\lambda) = 0 \Rightarrow [Q]^{\phi} \neq \lambda$.]
(Justified by FM.)

FUNC says. If $\hat{A}$ and $\hat{B}$ are two operators and there exists a function f s.t. $\hat{A} = f(\hat{B})$ then

$$[A]^{\phi} = f([B]^{\phi})$$

i.e. $[f(B)]^{\phi} = f([B]^{\phi})$.

Proof relies on FUNC holding for

$\hat{A} = f(\hat{B})$, $\hat{A} = g(\hat{C})$ $[\hat{B}, \hat{C}] \neq 0$.

So $[A]^{\phi} = f([B]^{\phi})$
$= g([C]^{\phi})$ — constraint on values for incompatible magnitudes

N.B. If $\hat{B}$, $\hat{C}$ are maximal $\hat{A}$ must be degenerate for this situation to arise.

Insertion

*

Extension of notation to two separated systems:

$$\left[Q \times I\right]^{\phi}_{\{\langle A, B\rangle\}}(D, E)$$

We can break FUNC and retain realism by supposing that [illegible] each r.a. [illegible] [illegible] [illegible] more [illegible] one magnitude

Thus we distinguish A_B, A_C

where $\{A_B\}^{\phi} \underset{Df}{=} f(\{B\}^{\phi})$

$\{A_C\}^{\phi} \underset{Df}{=} g(\{C\}^{\phi})$

In general we shall assume FUNC* which says. effectively

$A_B = A_C$, if $\hat{B}, \hat{C}$ are commuting maximal [illegible]

i.e. $\exists g$ s.t. $B = g(B)$

g is 1:1

Denote by $\{B\}$ equivalence class of all C s.t. $\exists g$ s.t. $C = g(B)$

then we write $[A]^{\phi}_{\{B\}} \underset{Df}{=} \{A_B\}^{\phi}$

N.B. FUNC* is consistent with and independent of VR.

This explicates Ontological Contextuality

But the value $[A]^{\phi}_{\{B\}}$ may also depend on the environment, in particular the apparatus set to measure some magnitude C

So we write $[A]^{\phi}_{\{B\}}(C)$

This explicates Environmental Contextuality

* Exercise

We now apply these notions to two separated systems.

For all Q, A, B, C, D, E, where $Q = h(A)$ and A, B, C, D and E are all nominal

OLOC

$$[Q \otimes I]^{\phi}_{\{\langle A, B\rangle\}}(D, E) = [Q \otimes I]^{\phi}_{\{\langle A, C\rangle\}}(D, E)$$

ELOC

$$[Q \otimes I]^{\phi}_{\{\langle A, B\rangle\}}(D, E) = [Q \otimes I]^{\phi}_{\{\langle A, B\rangle\}}(D, C)$$

where $\langle A, B\rangle$ is the nominal physical magnitude O for the joint system whose associated operator $\hat{O}$ is constructed by $\hat{A}$ & $\hat{B}'$ by the relation

$$\hat{O} = \sum_{ij} c_{ij} P_i \otimes P'_j$$

where $\hat{A} = \sum \alpha_i P_i$ $\quad \hat{B} = \sum \beta_i P'_i$

and $c_{ij} = F(\alpha_i, \beta'_j)$ where $F: \mathbb{R}^2 \to \mathbb{R}$ is 1:1

In words -

OLOC Locally nominal physical magnitudes on each of two spatially separated systems are not split, by ontological contextuality relative to the specification of different nominal physical magnitudes for the joint system

FLOC: the value possessed by a local physical magnitude cannot be changed by altering the arrangement of a remote piece of apparatus which forms part of the measurement context for the combined system.

NB (1) we do not assume OLOC in showing FLOC but FLOC is only violated [illegible] a locally possible [illegible] OLOC states.

(2) In terms of measurement results OLOC ≡ FLOC. both demonstrate a dependence of outcome recorded by apparatus connected to one system on the setting of the apparatus connected to the other (remote) system.

Redhead – Heywood Result

We shall show that

* $\mathrm{FUNC}^d \wedge \mathrm{VR} \wedge \mathrm{FLOC} \wedge \mathrm{OLOC}$

$\rightarrow$ Contradiction

Define Value Rule VR $\Rightarrow p_Q^{\phi}(\lambda)=0 \Rightarrow [Q]^{\phi} \neq \lambda$. (BKS type)

Preliminary Comments

Proofs of nonlocality via Bell Inequality have been charged with 'hidden' assumptions. As Fine remarked (1974) 'Hidden variables are one thing, hidden assumptions another'

Fine has claimed (1974) that Bell's original type of proof involved FUNC in the form of the Product Rule (J D assumption that QM joints and phase-space joints were identical)

Anyway Fine said we are committed to joint distributions for non-commuting observables even in the Eberhard type of proof (1982) (On h.v. approaches this is true)

But Fine is mistaken here.

Bell → Kolm. joints

Kolm. joints → self joints in a model.

But this model need not be the real world!

However all proofs of non-locality via Bell's theorem do involve reflections of probability theory that might be challenged.

Query Can we give a purely algebraic proof of non locality?

Question posed by Bub (1976) in the form:

Is it possible to extend Maczynski's Theorem (1971) to locally maximal observables?

M's Theorem says we do not need ~~ontological~~ contextuality to allow value assignments to maximal observables

If M's theorem cannot be extended this would mean locally maximal observables must be ontologically contextual ⟹ violation of OLC

Unfortunately Demopoulos, Bub, Humphreys have shown that M's [illegible] can be extended to locally maximal observables.

So OLOC need not be violated

Our result shows however that if we are to retain Fine's VR then OLOC and ELOC do both most fail.

Violating OLOC means we cannot specify a locally maximal observable independently of properties relating to the whole combined system
— leads to ontological holism in which it is impossible to make sense of a realist construal of QM that considers properties independently with each of two separated systems

Violating ELOC (if OLOC is assumed) is the sort of non locality envisaged in the Bell-type non locality arguments.

The steps in the proof of $\not\exists$ are as follows:

1.) Derive EVR from VR and FUNC*

EVR: If $\hat{Q}_1$ and $\hat{Q}_2$ commute and $\hat{R}$ is maximal operator s.t. $\hat{Q}_1 = f(\hat{R})$, $\hat{Q}_2 = g(\hat{R})$

Then $P^{\phi}_{Q_1, Q_2}(\lambda, \mu) = 0 \Rightarrow$

$$[Q_1]^{\phi}_{\{R\}}(R) \neq \lambda$$

$$\text{or } [Q_2]^{\phi}_{\{R\}}(R) \neq \mu .$$

N.B. EVR for general commuting Q_1, Q_2 is not derivable from VR and Func* and $\Rightarrow$ FUNC, since contradictory. This was proved by Fine in 1974.

2.) As a special case of EVR we obtain, if $\hat{Q} = h(\hat{A})$, $\hat{Q}' = k(B)$ where A, B are maximal

$$P^{\phi}_{Q\otimes I, I\otimes Q'}(x, y) = 0$$

$$\Rightarrow [Q\otimes I]^{\phi}_{\{\langle A,B\rangle\}}(A, B) \neq x$$

$$\text{or } [I\otimes Q']^{\phi}_{\{\langle A,B\rangle\}}(A, B) \neq y$$

3) Incompatibility of EVR and Locality

Consider correlated state of 2 separated systems
$$\Psi = \sum c_m \, |a_m\rangle \otimes |b_m\rangle$$
$\hat{A}$ has eigenvalues $a_1, \ldots a_N$
$\hat{B}$ — — — $b_1, \ldots b_N$.

Consider non maximal operator $\hat{Q}$ s.t.
$\hat{Q} = f(\hat{A}) = g(\hat{A}')$ for maximal $\hat{A}, \hat{A}'$
where $[\hat{A}, \hat{A}'] \neq 0$.

Then it is easy to show that

$$[A \otimes I]^{4}_{\{\langle A,B\rangle\}}(A,B) = a_m \qquad (1)$$
$$\Rightarrow [I \otimes B]^{4}_{\{\langle A,B\rangle\}}(A,B) = b_m.$$

and $\{I \otimes B\}^{4}_{\{\langle A',B\rangle\}}(A',B) = b_m$

$$\Rightarrow [F(A \otimes I)]^{4}_{\{\langle A',B\rangle\}}(A',B) = f(a_m) \qquad (2)$$

Now Apply ELOC & OLOC to equate

$$[I \otimes B]^{4}_{\{\langle A,B\rangle\}}(A,B) = \{I \otimes B\}^{4}_{\{\langle A',B\rangle\}}(A',B)$$

whence we obtain FUNC**

$$[f(A \otimes I)]^{4}_{\{\langle A',B\rangle\}}(A',B) = f\left([A \otimes I]^{4}_{\{\langle A,B\rangle\}}(A,B)\right)$$

This is not quite FUNC which would have same environmental context on both sides of eq.
But can it be used to demonstrate a K-S type contradiction by following thru argument parallel to that used by K-S in their 1967 paper
for product state of 2 spin-1 systems

Comments

1.) Fine (1977) and Stairs (1978) claimed CVR was contradictory

But we have derived CVR as a theorem from VR and Fact*.

Explanation: CVR would be contradictory if we did not allow for violation of locality — this is flaw in the work of Fine and Stairs

2.) Minimal, transparent use of probability theory — On more A QM is non-local

3.) What about stochastic h.v. theories where measurement results are stochastically related to the hidden state of the micro system (so FM is given up). The Eberhard-type proof now fails because of PLCD being inapplicable. VR is not applicable so our approach does not apply.

Bell Theorem can be proved if we identify Locality = factorizability.

Perhaps we just have to give up factorizability — cp Fine.

Final remarks

Interaction of Physics and Philosophy

Either 1) Physics should be changed in the light of philosophical preconceptions

or 2.) Philosophical ideas should be modified in the light of new theories in physics.

Role of philosophy of physics as I see it is to show what total packages are available — then choice is matter for argument but not decisively settleable.

(Ideal book on physics) — slide (0)

The role of philosophy in physics then is to promote understanding of what physics really is commmunicating to us.

Of course theoretical physicists do use philosophical analysis of a sort in their work — Einstein and Bohr are notable examples. However in the case of Einstein general relativity notoriously fails to implement his philosophy, while Bohr gives us a very unclear mish-mash of Kierkegaard, Kant and William James, to mention some of his sources.

But the surprising thing is that muddled philosophy is quite consistent with splendid physics.

In a sense one could claim that Einstein did not understand relativity

not Bohr quantum mechanics, but then one can do physics without understanding it rather like riding a bicycle without knowing anything about rigid-body dynamics. But how much better to do physics and understand it, to combine the study of physics with the study of philosophy of physics